Regolith-Derived Heat Shield for Planetary Body Entry and Descent System with In-Situ Fabrication

Michael D. Hogue, NASA Kennedy Space Center
Robert P. Mueller, NASA Kennedy Space Center
Laurent Sibille, QNA ESC Kennedy Space Center
Paul E. Hintze, NASA Kennedy Space Center
Daniel J. Rasky, NASA Ames Research Center

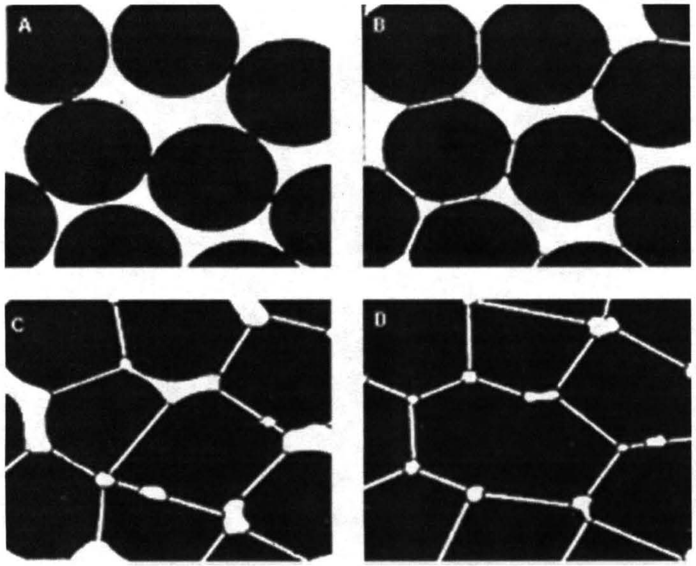
Introduction

- High-mass planetary surface access is one of NASA's Grand Challenges involving entry, descent, and landing (EDL).
- Heat shields fabricated in-situ can provide a thermal protection system for spacecraft that routinely enter a planetary atmosphere.
- Fabricating the heat shield from extraterrestrial regolith will avoid the costs of launching the heat shield mass from Earth.
- This project investigated three methods to fabricate heat shield using extraterrestrial regolith and performed preliminary work on mission architectures.

Fabrication Methods Being Investigated

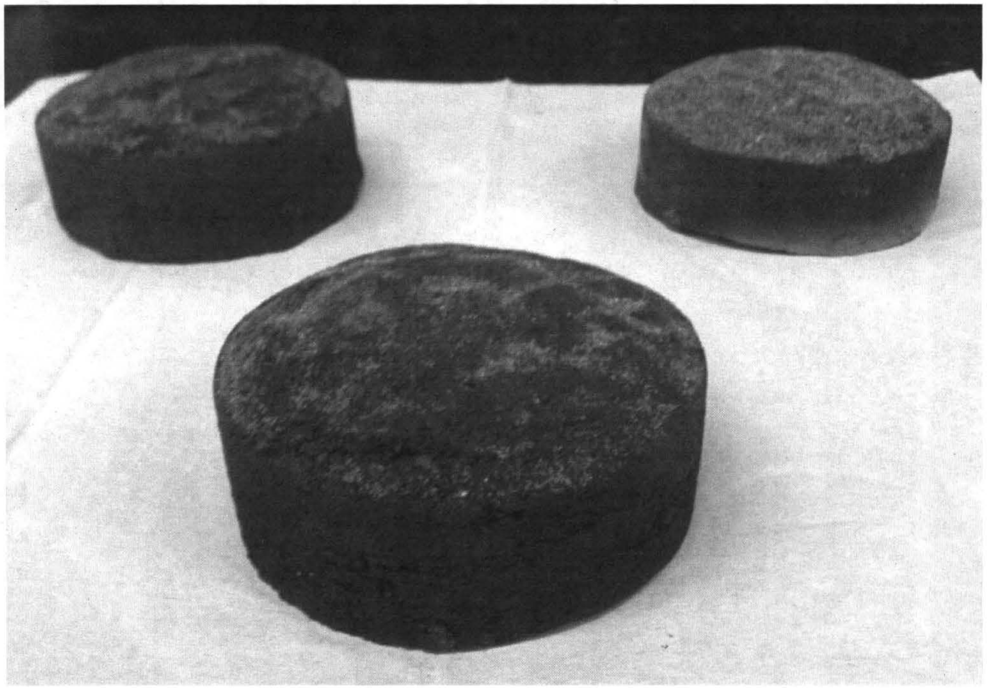
- Sintering of regolith
  - Furnace sintering
  - Solar sintering (deferred until phase II)
- Hot post-process regolith from in-situ resource utilization (ISRU) devices
  - ISRU processes to derive O_2 and other materials from regolith leaves a hot slag or glassy melt as a waste stream.
  - This hot regolith can be poured into a heat shield mold form.
- High temperature RTV or polymer binder

Sintering Process



Temperature and heating time are crucial factors in the resulting structure and density.

JSC-1AC regolith simulant sintered tiles



ISRU Process Waste

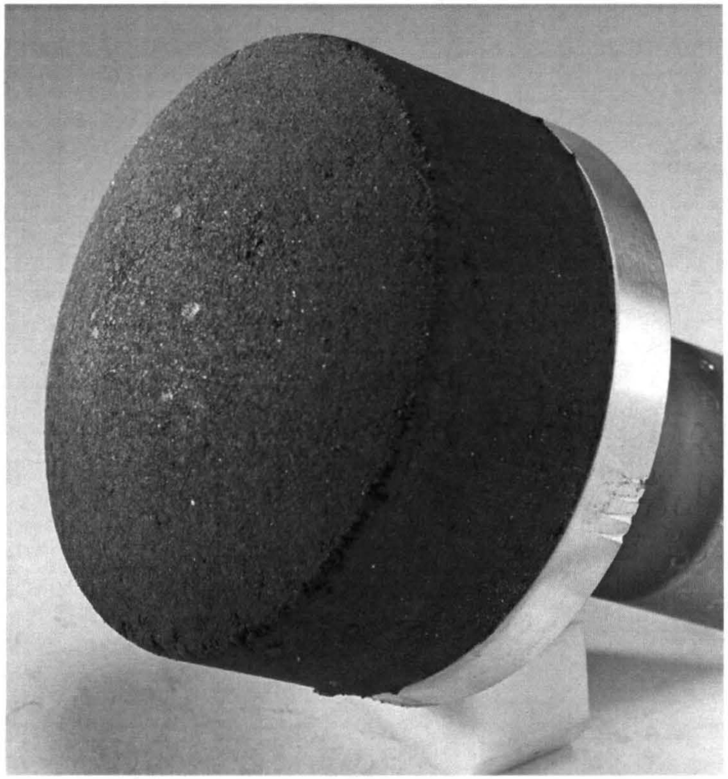
Hot Hawaiian tephra output from the ROxygen generation I oxygen production reactor.

Use of waste stream from ISRU processes.

- Hot regolith can be poured into a heat shield mold.
- Saves energy by combining processes.

We discarded the use of fully melted stream materials because their higher density, higher thermal conductivity and generally weaker mechanical strength once solidified make them less desirable candidates for heat shield applications.

High Temperature RTV Binder

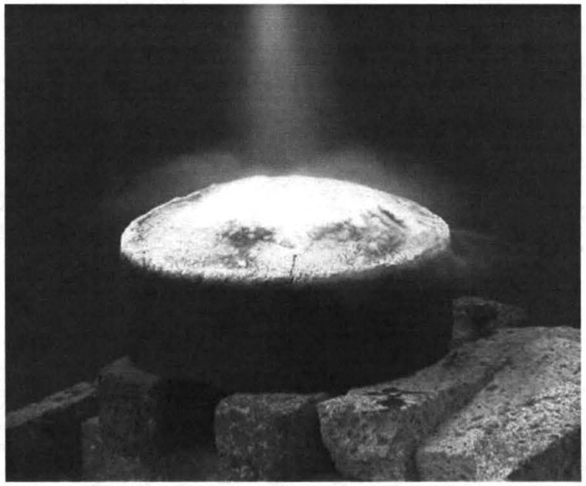


Regolith heat shield test sample made From JSC-1A Lunar simulant using a high temperature silicone RTV binder.

- A high temperature silicone RTV was investigated as a binding agent for the regolith.
- Several RTV/regolith ratios were developed.

Flame Impingement Testing

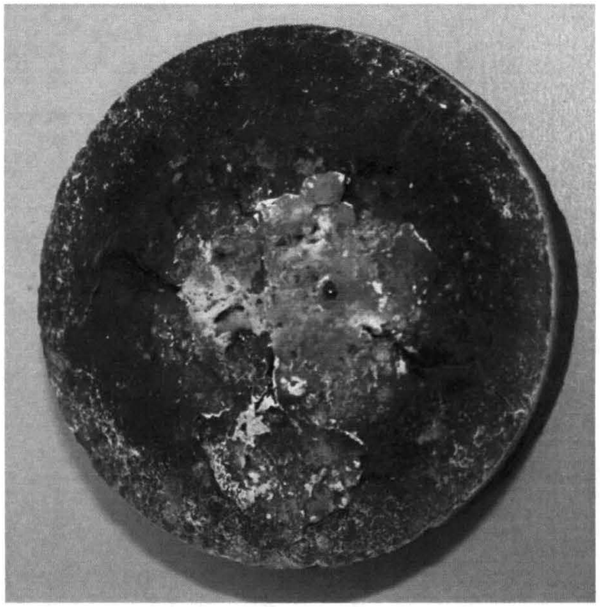
- KSC has fabricated several furnace sintered and RTV bound test samples using both JSC-1A Lunar and JSC-1 Martian regolith simulants.
- These samples were evaluated by being subjected to flame impingement tests (via a welding torch).
- All samples (sintered and RTV bound) had good results from the flame impingement testing.



Test sample made from JSC-1A Lunar simulant and a high temperature RTV rubber undergoing flame impingement testing.

Flame Impingement Testing

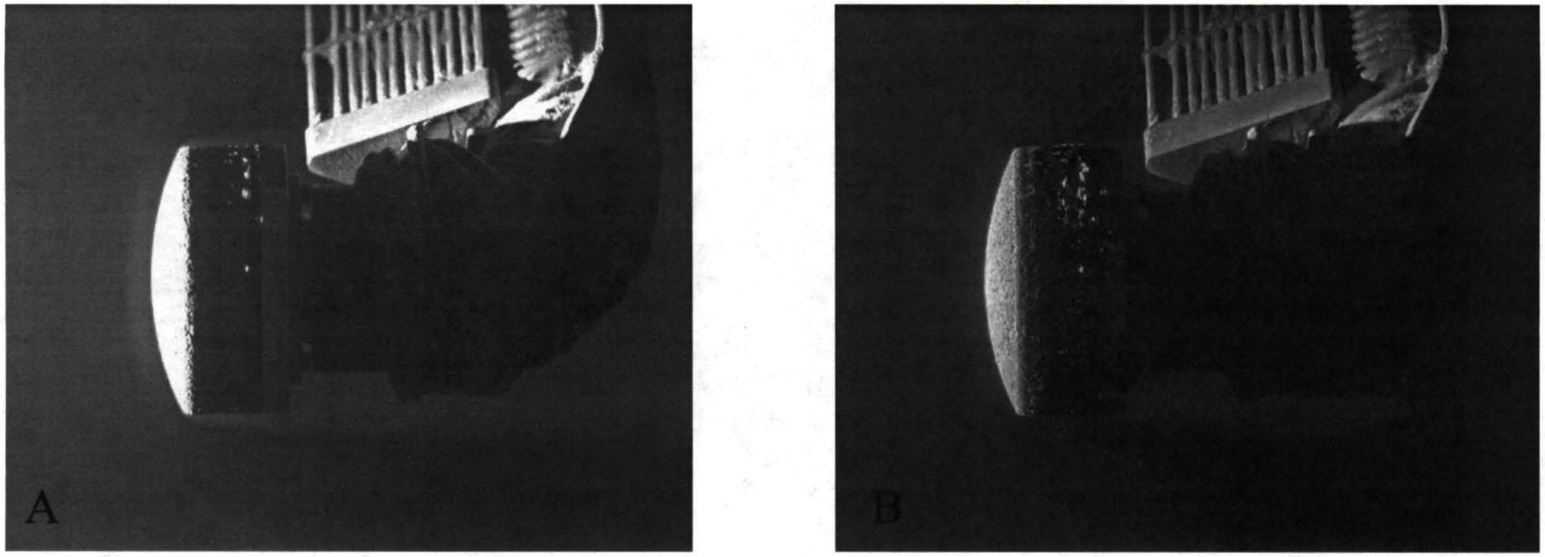
- The torch (~2200° C) was 6" away from the front surface of the test samples.
- Each test sample was exposed for five minutes.
- Maximum rear surface temperature (measured several minutes after test end) was 52.9° C).



Front surface of RTV bound sample after flame impingement test showing charring and some ablation.

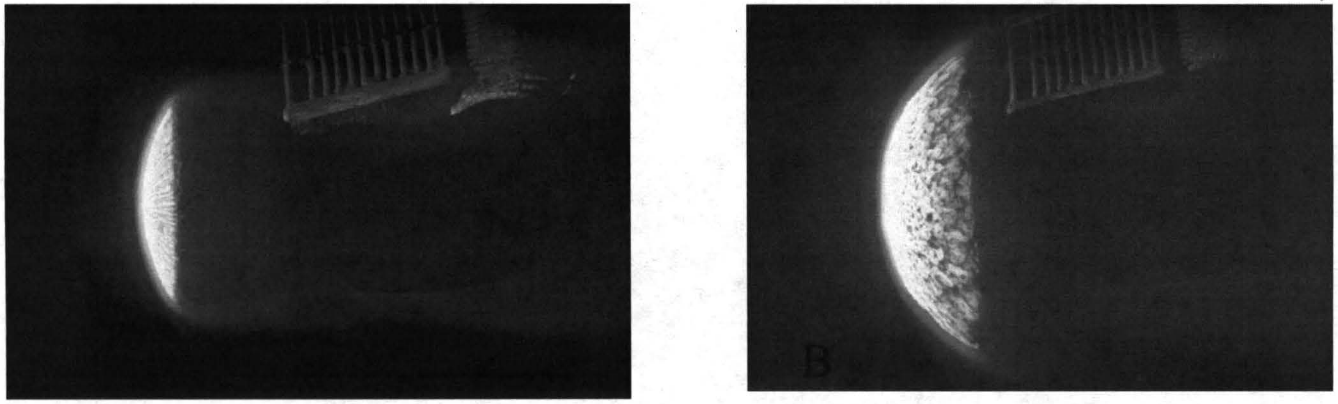
Arc Jet Testing

- KSC fabricated ten regolith simulant coupons for testing at the arc jet facility at Ames Research Center
- The arc jet facility can model the thermal and kinetic environment of atmospheric entry via high speed hot plasma impingement.

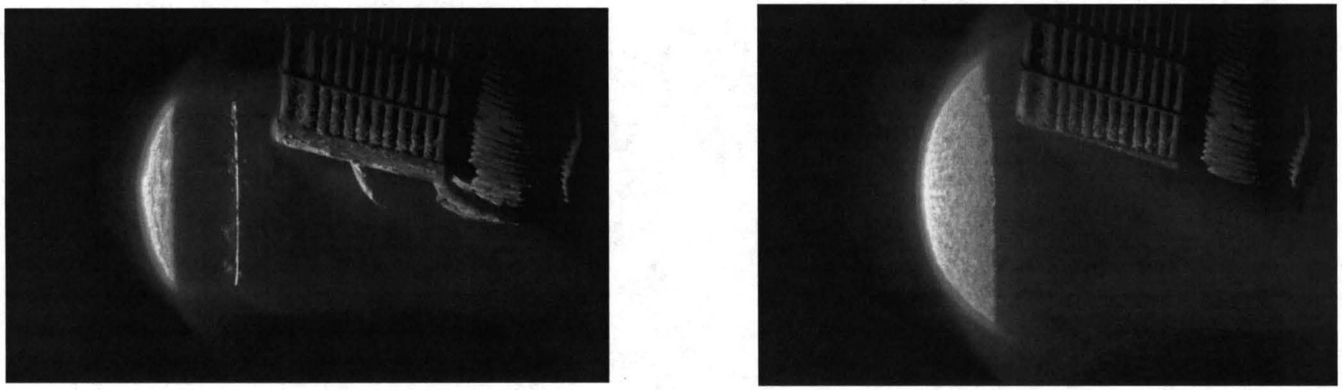


A. JSC-1 Mars/RTV at the start of run. B. The same sample at the end of a 150 second exposure at 48 W/cm^2 showing little or no melting or ablation.

Arc Jet Testing



A. JSC-1A Lunar/RTV at the start of run. B. The same sample at the end of a 240 second exposure at 92 W/cm^2 showing melting and flow of its surface.

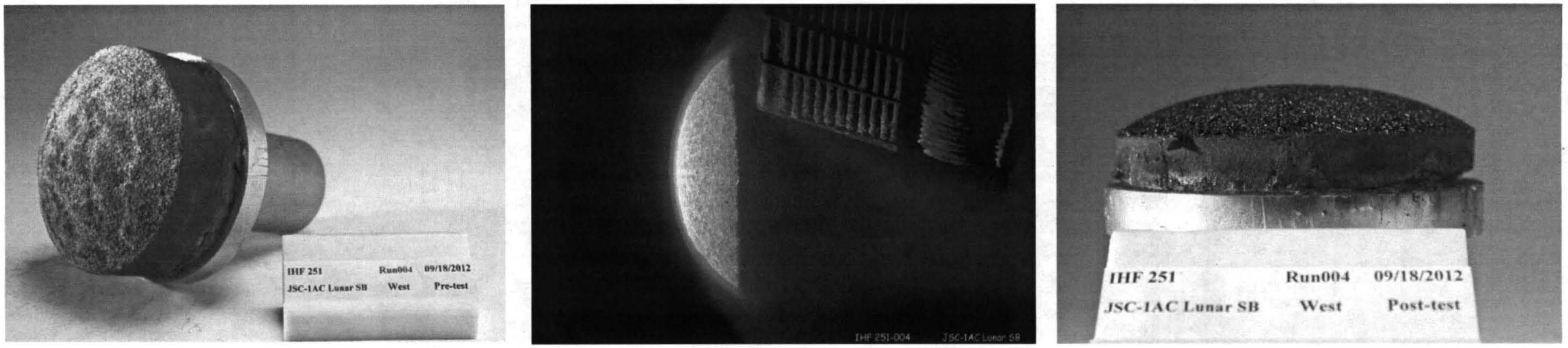


A. JSC-1AC Lunar Sintered "B" at the start of run. B. The same sample at the end of a 300 second exposure at 92 W/cm^2 showing melting and flow of its surface.

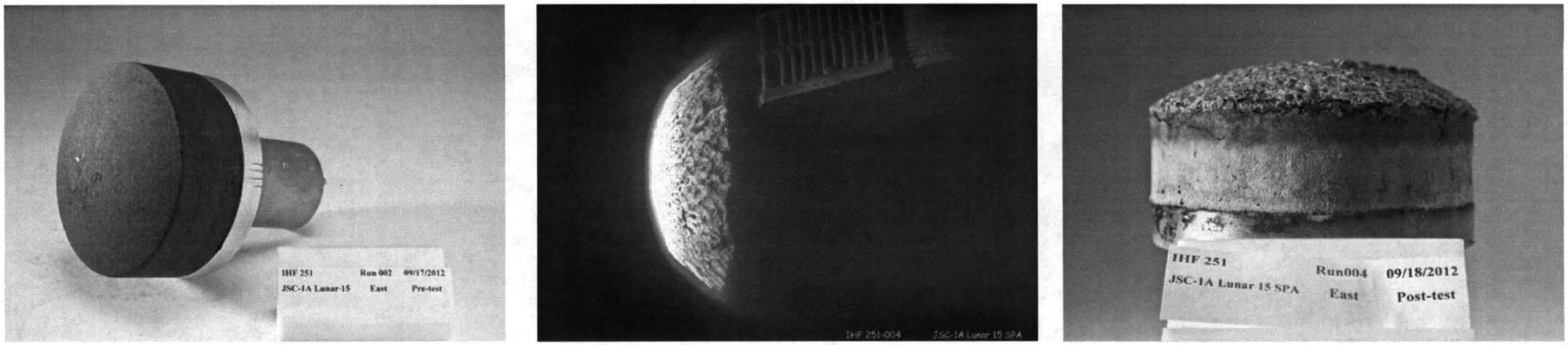
Arc Jet Testing

- In the higher heating condition (five minutes at 92 W/cm^2 – equivalent to space shuttle re-entry) ablation and melting of front surfaces were noted.
- All ten samples (sintered & RTV bound) provided adequate dynamic and thermal protection to their rear surfaces (maximum temperature ~ 262° C recorded several minutes after test end).

Pre-Test, Test, and Post-Test Sample Photos

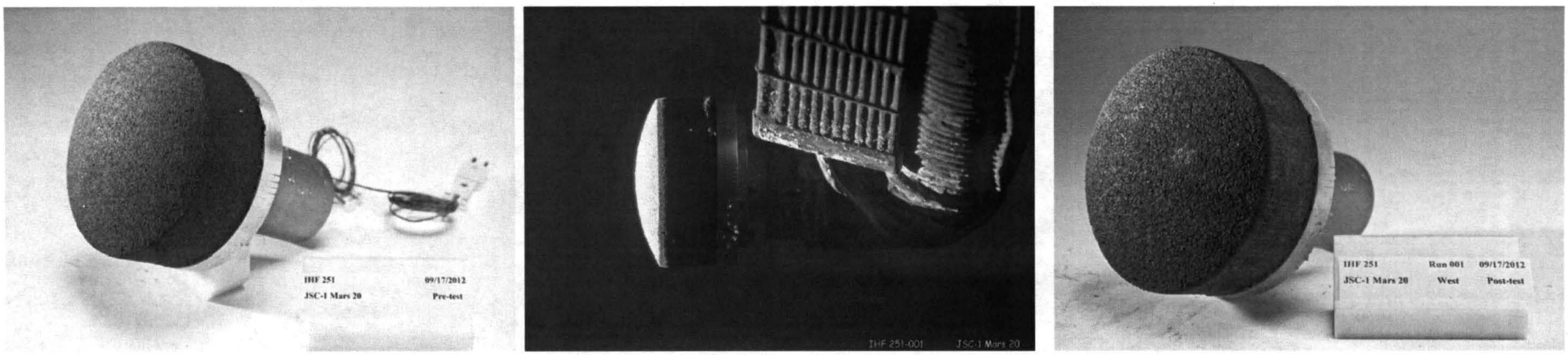


Sintered JSC-1AC Lunar Simulant



RTV Bound JSC-1A Lunar Simulant

Pre-Test, Test, and Post-Test Sample Photos



RTV Bound JSC-1 Martian Simulant

Arc Jet Test Videos

Interaction Heating Facility (IHF)
Ames Research Center
September, 2012

Architecture

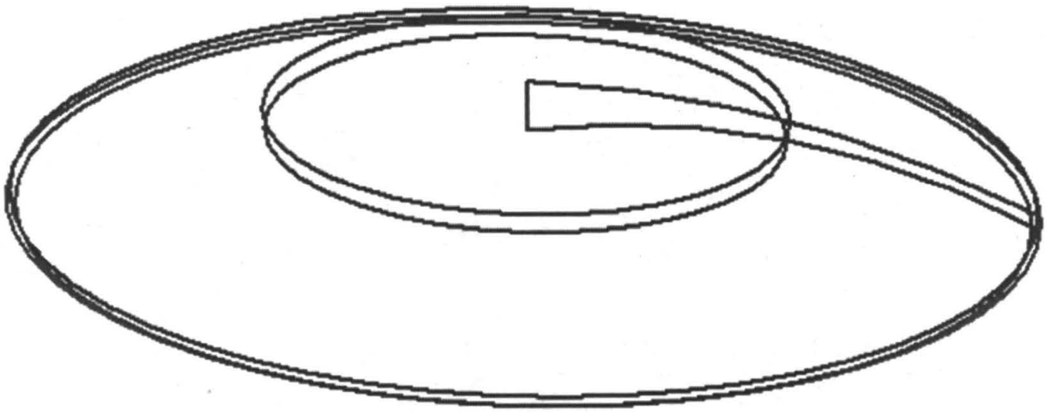
- Initial Architecture benchmark is the Mars NASA Design Reference Architecture (DRA) 5.0 modified to use Mars entry heat shields fabricated on Phobos or Deimos.
- With a TPS mass of 40.7 metric tons and a gear ratio* of 5, the LEO to **Mars Mass savings is 203.5 metric tons**.
- Using expendable launch vehicles (~$8,800/kg) the cost savings per Mars mission is $1.79 Billion.
- With 10 crew rotations and 10 cargo missons in a Mars campaign using the regolith heat shields, the total cost savings would be <u>**about $35.8 billion.**</u>

* Gear ratio is the ratio of mass required in LEO to deliver one mass unit to Mars orbit.

Design Reference Architectures

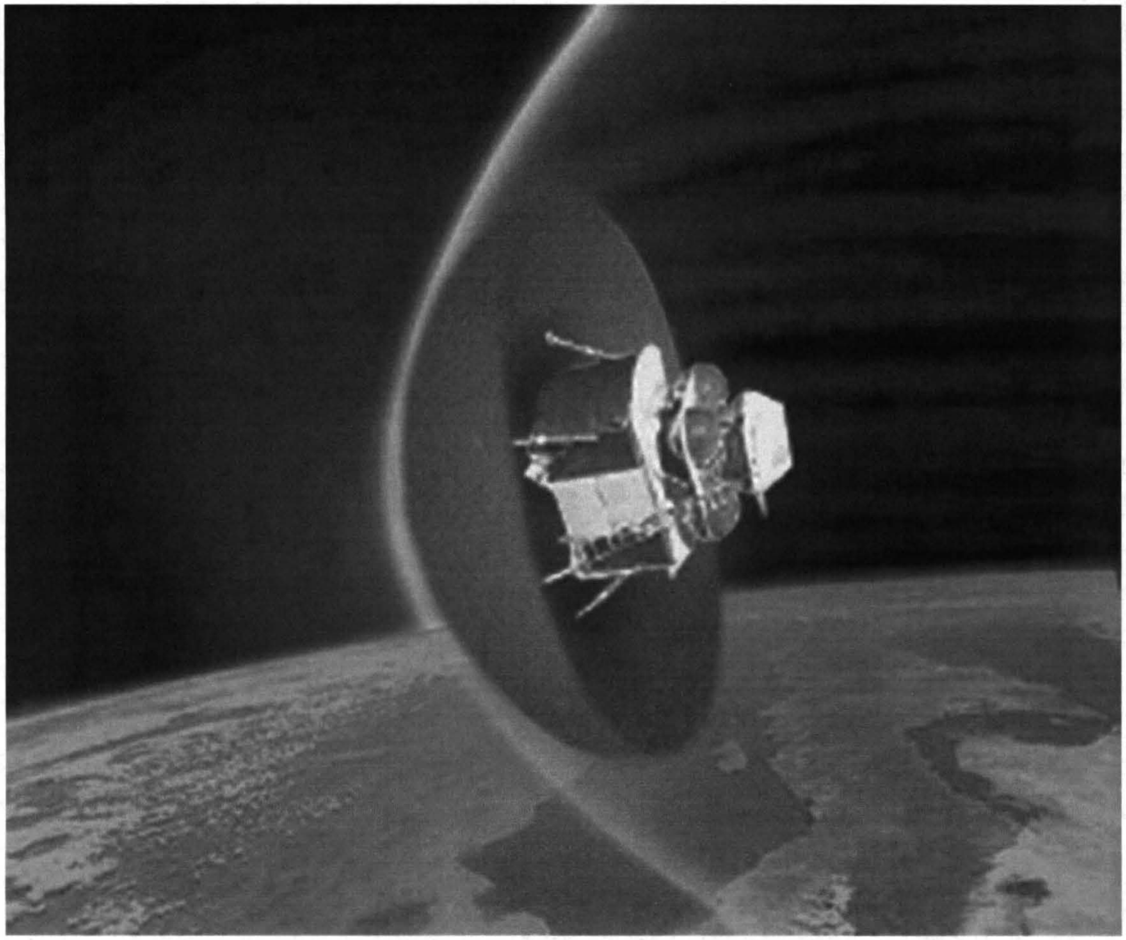
- Architecture I – In Situ Heat Shield Fabrication at Phobos/Deimos for Earth-bound Mars Return Spacecraft and Mars EDL of Surface Exploration Craft.
- Architecture II – Lunar Heat Shield Fabrication Facility for Moon-Earth Returns and Moon-Mars Missions. Determined to be not economical due to the Δv requirements of launch from Lunar surface.
- Architecture III: In Situ Heat Shield Fabrication at Asteroid for Earth-bound Spacecraft.

Architecture

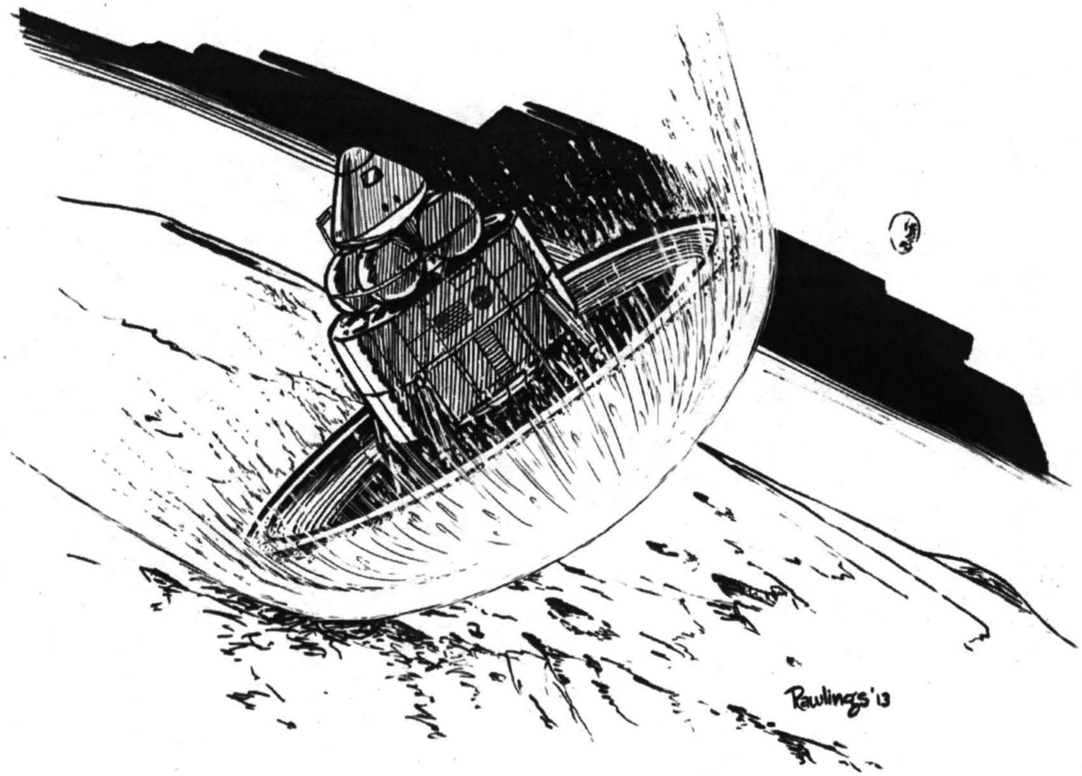


Blended Conic Elliptical Heat Shield Notional Concept

Preliminary Artist's Concept of a Regolith-Derived Heat Shield



Concept Art Work by Pat Rawlings



Manned lander entering the Martian atmosphere using a regolith derived heat shield fabricated on Phobos

Summary

- Building a viable heat shield in-situ from regolith will greatly reduce the transport costs of Missions to Mars or other bodies where atmospheric entry is required.
- Three in-situ fabrication techniques were investigated to build the heat shields. Full melt ISRU generated waste stream was eliminated due to high thermal conductivity and brittleness.
- Test samples of sintered and RTV bound formulations performed well in flame impingement and arc jet testing. Further work will be needed to optimize processes.
- Architectures are being developed for optimal use of regolith derived heat shields.

The investigators would like to acknowledge NIAC, the Kennedy Space Center, and Ames Research Center for their support of this project.

Questions?